# SIMULATION OF THE PERFORMANCE OF MICROWAVE MESFETs USING A DISTRIBUTED MODEL

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**Abstract**

A MESFET distributed model that accounts for transversal propagation effects is used to simulate a medium power MESFET. It is shown that distributed effects become important in practical devices and, therefore, cannot be ignored.

**Introduction**

Lumped-element circuit theory is a convenient approximation for electromagnetic problems when their dimensions are much smaller than the wavelength. When the wavelength is comparable to the dimensions of the structure under analysis, this approximation is not valid any longer. Unfortunately, it seems that this fact is not widely taken into consideration when modelling semiconductor devices operating at millimeter-wave frequencies when using equivalent circuits.

The MESFET electrode layout can be considered as a three-conductor transmision line with a non-homogeneous substrate that can support two quasi-TEM modes. In this paper, a distributed equivalen circuit is used in conjunction with couple-mode theory to simulate the propagation characteristics of the structure. It is shown that transversal propagation phenomena can be significant in MESFET devices.

**The MESFET distributed model**

The distributed model [1] for the intrinsic MESFET is shown in Fig. 1. Coupled-mode theory [2,3] is used to obtain analytical expressions for the four port S-parameters of the intrinsic device. The intrinsic two port S-parameters for a given device layout can be easily calculated from the four port S-parameters by open-circuiting the appropriate ports. Parasitics elements are added to the distributed model in order to simulate the effects of bonding wires, bonding pads and via holes (see Fig. 1).

**Simulation of a medium-power MESFET**

A medium power MESFET (Fujitsu FLK022XV), in the common source configuration, has been used to study the capabilities of the distributed model presented in this paper.

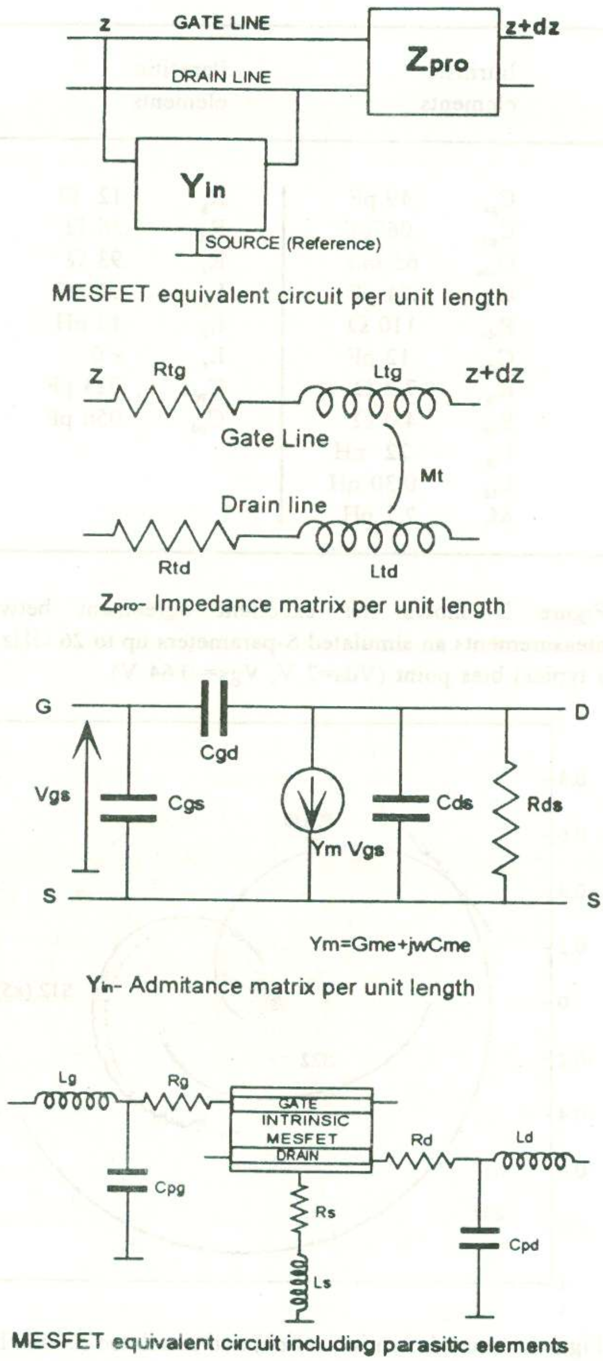


Fig.1. MESFET proposed distributed model

The element values have been obtained by fitting the measured S-parameters using an optimization procedure.

To avoid unwanted effects, the parasitics element values where obtained by averaging the results corresponding to a set of different bias points. This procedure provides an interesting confirmation of the distributed model consistency since these parasitic elements are almost bias-independent. In a second step, the intrinsic element values were calculated after linearizing, i.e, keeping constant the extrinsic elements. In Table 1, extrinsic and intrinsic element values are shown.

Table 1: Element values for the distributed model

| Intrinsic elements | | Parasitic elements | |
|---|---|---|---|
| $C_{gs}$ | .49 pF | $R_g$ | .12 Ω |
| $C_{gd}$ | .067pF | $R_d$ | .36 Ω |
| $G_{me}$ | 65 mS | $R_s$ | .93 Ω |
| $C_{me}$ | .21 pF | $L_g$ | .12 nH |
| $R_{ds}$ | 110 Ω | $L_d$ | .13 nH |
| $C_{ds}$ | .12 pF | $L_s$ | ≈ 0 |
| $R_{tg}$ | 7.2 Ω | $C_{pg}$ | .013 pF |
| $R_{td}$ | 4.0 Ω | $C_{pd}$ | .056 pF |
| $L_{tg}$ | .22 nH | | |
| $L_{td}$ | 0.30 nH | | |
| $M_t$ | 2.2 pH | | |

**Figure 2 shows the excellent agreement between measurements an simulated S-parameters up to 26 GHz for a typical bias point (Vds=2 V, Vgs=-0.64 V).**

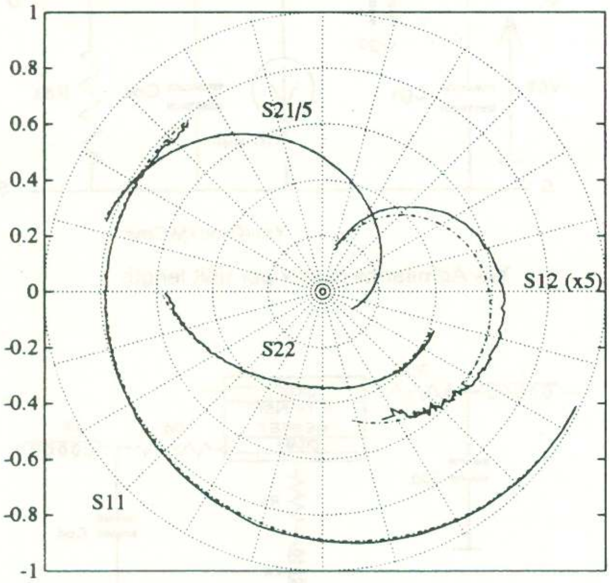


**Fig.2. Measured (continous line) and simulated (dotted line) S-parameters using the distributed model (1-26 GHz)**

**Propagation parameters**

The propagation constants of the two quasi-TEM modes supported by the device electrodes can be computed from the model and the element values shown in Table 1. These parameters provide some useful information regarding the distributed behaviour of the device. For example, the real and imaginary parts of the two propagation constants shown in Fig. 3 indicate that losses are not negligible in this device, and that phasing effects are significant in the range of measurement. In fact, $\beta_g l$, the imaginary part of $\gamma_g l$, is $\pi/2$ at about 20 GHz, i.e., the length of the device for the gate mode is $\lambda/4$ at this frequency. This resonant behaviour is clearly seen in the admitance parameters of the intrinsic device presented in Fig. 4.

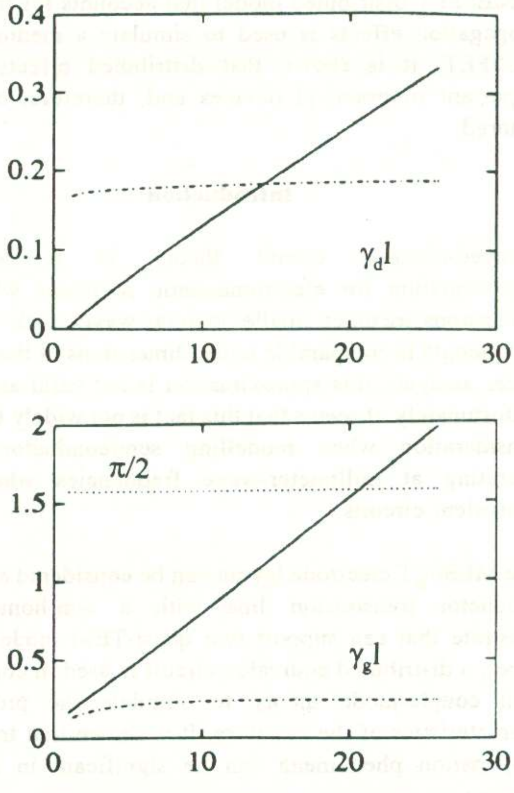


**Fig.3. Real (dotted line) and imaginary (continous line) parts of propagation constants versus frequency (1-26 GHz)**

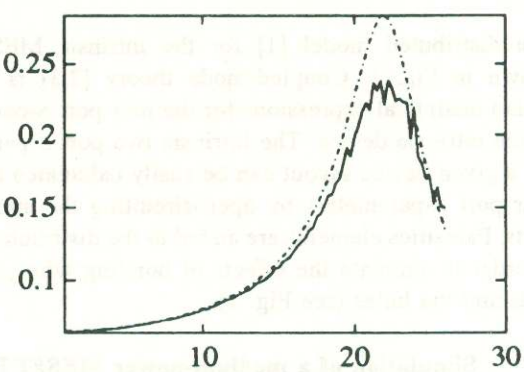

**Fig.4. Measured (continous line) and simulated (dotted line) $Y_{21}$ intrinsic MESFET parameter (1-26 GHz)**

The results shown in Figs. 3 and 4 indicate that lumped-element equivalent circuits cannot provide a physically realistic simulation of the device.

The four characteristic impedances of the two quasi-TEM modes can also be computed from the model. The real and imaginary parts of two of them are shown in Fig. 5.

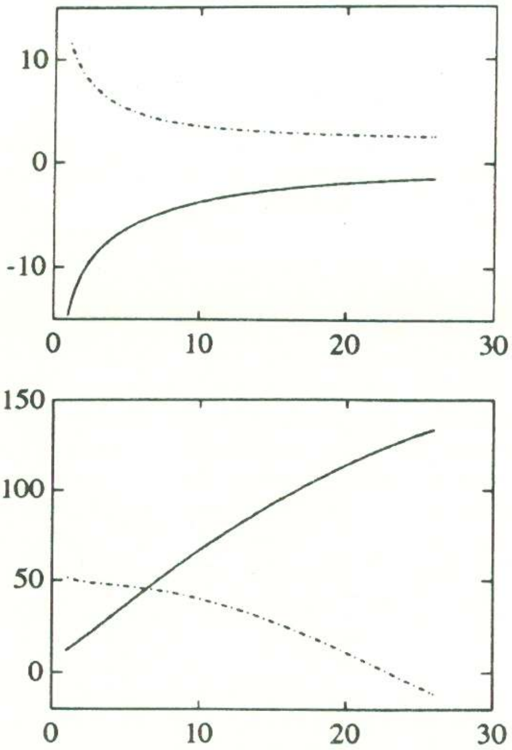


Fig. 5. Real (dotted line) and imaginary (continous line) parts of MESFET characteristic impedances versus frequency (1-26 GHz)

### Comparison with a lumped-element equivalent circuit

In order to assess the performance of the proposed MESFET distributed model, a standard lumped-element equivalent circuit [4] has also been used to simulate the same measured S-parameters. The results are shown in Fig. 6 and Table 2.

Figure 6 shows that the performance of Vendelin's model is similar to that of the distributed model (see Fig. 2). On the other hand, Table 2 suggests that the main differences between the two models are the values for the parasitic elements. In Vendelin's model, $L_g$, $L_d$, $L_s$, $C_{pg}$ and $C_{pd}$ are greater than those of the distributed one.

A first-order approximation of the distributed model shows that, at low frequencies, when the products $\gamma_g l$ and $\gamma_d l$ are small, the effect of transversal propagation can be simulated by a simplified lumped-element equivalent circuit composed of series connecting a fraction of the propagation impedance matrix ($Z_{pro}$) and the semiconductor intrinsic impedance matrix $(Y_{in})^{-1}$. This could explain the good fitting and the excess of parasitic elements provided by standard lumped-element equivalent circuits, like the one proposed in [5]. It could also explain the significant bias dependence observed in the parasitic elements [5] since the intrinsic device contributes to the value of these elements when simulated by means of a lumped-element equivalent circuit.

Table 2: Vendelin's equivalent circuit element values

| Intrinsic elements | | Parasitic elemets | |
|---|---|---|---|
| $C_{gs}$ | .35 pF | $R_g$ | .24 Ω |
| $C_{gd}$ | .053pF | $R_d$ | .55 Ω |
| $g_m$ | 100 mS | $R_s$ | 5.8 Ω |
| τ | .27 pS | $L_g$ | .20 nH |
| $R_{ds}$ | 71 Ω | $L_d$ | .14 nH |
| $C_{ds}$ | .054 pF | $L_s$ | .045 nH |
| $R_i$ | 3.1 Ω | $C_{pg}$ | .26 pF |
| $R_f$ | 42 Ω | $C_{pd}$ | .16 pF |

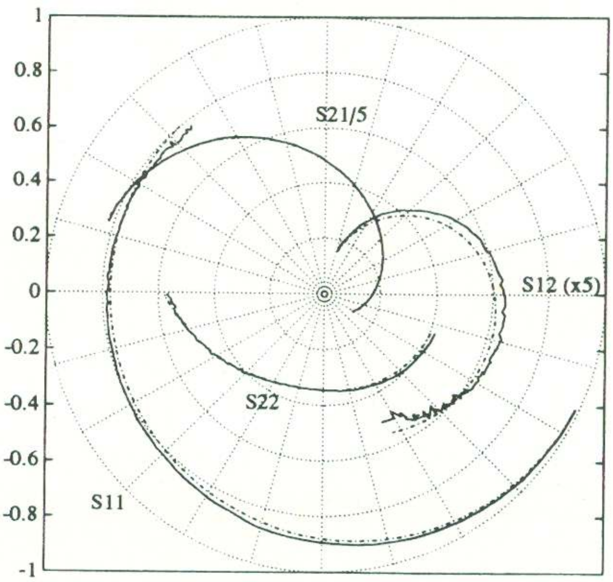


Fig. 6. Measured (continous line) and simulated (dotted line) S-parameters using Vendelin's model (1-26 GHz)

### Conclusions

A MESFET distributed model that accounts for transversal propagation effects has been presented. The results obtained show that distributed effects are significant in practical devices and therefore cannot be ignored.

It has also been shown that distributed models are required to simulate the performance of MESFET devices at millimeter-wave frequencies.

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